

Power Output Apparatus, Motor Driving Method and Computer-Readable Recording
Medium Having Program Recorded Thereon for Allowing Computer to Execute Motor
Drive Control

5 This nonprovisional application is based on Japanese Patent Application No.
2003-129338 filed with the Japan Patent Office on May 7, 2003, the entire contents of
which are hereby incorporated by reference.

BACKGROUND OF THE INVENTION

Field of the Invention

10 The present invention relates to a power output apparatus. In particular, the
present invention relates to a power output apparatus using a double-winding motor, a
motor driving method for driving a double-winding motor, and a computer-readable
recording medium having a program recorded thereon for allowing a computer to
execute motor drive control.

15 Description of the Background Art

A conventional power output apparatus using a double-winding motor is
known from Japanese Patent Laying-Open No. 2002-218793. Referring to Fig. 14,
this conventional power output apparatus 300 includes a double-winding motor 310, a
DC (direct current) power supply 320, inverters 330 and 340 and a capacitor 350.

20 Double-winding motor 310 includes two three-phase coils 311 and 312. DC
power supply 320 is connected between respective neutral points of three-phase coils
311 and 312.

Inverter 330 includes three arms corresponding respectively to the U-phase coil,
V-phase coil and W-phase coil of three-phase coil 311 and controls energization of
25 three-phase coil 311. Inverter 340 also includes three arms corresponding respectively
to the U-phase coil, V-phase coil and W-phase coil of three-phase coil 312 and controls
energization of three-phase coil 312. Capacitor 350 and inverters 330 and 340 are
connected in parallel between a positive-pole bus 301 and a negative-pole bus 302.

It is supposed here that a difference in potential between the neutral point of three-phase coil 311 and the neutral point of three-phase coil 312 is represented by V_{012} and a voltage of DC power supply 320 is represented by V_b . When there is a relation $V_{012} < V_b$ between the potential difference and the power-supply voltage, a DC current flows from DC power supply 320. The DC current flowing from DC power supply 320 is accumulated in one of the U-, V- and W-phase coils of three-phase coil 311 or 312 by switching control of corresponding one of the arms of inverter 330 or 340 so as to finally charge capacitor 350. In other words, one of the U-, V- and W-phase coils of three-phase coils 311 and 312 and corresponding one of the arms of inverters 330 and 340 constitute a voltage step-up converter to increase DC voltage V_b to an arbitrary level and thereby charge capacitor 350.

On the contrary, when there is a relation $V_{012} > V_b$, a terminal-to-terminal voltage of capacitor 350 is decreased by one of the arms of inverters 330 and 340 and one of the U-, V- and W-phase coils of three-phase coils 311 and 312 that corresponds to the above-mentioned arm so as to charge DC power supply 320.

With the terminal-to-terminal voltage of capacitor 350, inverters 330 and 340 control energization of three-phase coils 311 and 312 to drive double-winding motor 310. Depending on drive conditions of double-winding motor 310, a voltage to be applied to each phase coil of three-phase coils 311 and 312 varies and consequently, potential difference V_{012} between respective neutral points of three-phase coils 311 and 312 is larger or smaller than DC voltage V_b . Then, there arise the mode of charging capacitor 350 by DC power supply 320 and the mode of charging DC power supply 320 by capacitor 350 as described above.

In power output apparatus 300, DC voltage V_b of DC power supply 320 is increased to an arbitrary level by means of a part of the coils of double-winding motor 310 so as to charge capacitor 350. Then, by the terminal-to-terminal voltage of the charged capacitor 350, double-winding motor 310 is driven. Further, the terminal-to-terminal voltage of capacitor 350 is decreased to charge DC power supply

320.

Japanese Patent Laying-Open No. 2002-218793, however, does not disclose a power output apparatus applied to a hybrid vehicle of mechanical distribution type.

SUMMARY OF THE INVENTION

5 An object of the present invention is therefore to provide a power output apparatus suitable for hybrid vehicles of mechanical distribution type.

 Another object of the present invention is to provide a motor driving method suitable for hybrid vehicles of mechanical distribution type.

10 Still another object of the present invention is to provide a computer-readable recording medium having a program recorded thereon for allowing a computer to execute motor drive control that is suitable for hybrid vehicles of mechanical distribution type.

 According to the present invention, a power output apparatus includes a first inverter, a second inverter, a 2Y motor, a power supply, a capacitor element and a
15 control unit. The 2Y motor has a first three-phase motor coil and a second three-phase motor coil functioning as stators, and energization of the first and second three-phase motor coils is controlled respectively by the first and second inverters. The power supply is connected between a first neutral point of the first three-phase motor coil and a second neutral point of the second three-phase motor coil. The capacitor element is
20 provided on an input side of the first and second inverters. The control unit controls the first or second inverter to allow a precharge operation for precharging the capacitor element to be performed.

 Preferably, the control unit controls the first and second inverters to allow a voltage step-up operation for increasing a power-supply voltage which is output from
25 the power supply as well as a drive operation for driving the 2Y motor to be performed after the precharge operation is completed, and the 2Y motor starts an internal combustion engine.

 Preferably, the precharge operation refers to an operation of increasing a

power-supply voltage which is output from the power supply to allow an output voltage of the capacitor element to be at least a reference value.

5 Preferably, the first inverter includes three arms provided correspondingly to the first three-phase motor coil, and the second inverter includes three arms provided correspondingly to the second three-phase motor coil. The precharge operation is performed by using all phase coils of the first three-phase motor coil and the three arms of the first inverter or using all phase coils of the second three-phase motor coil and the three arms of the second inverter.

10 Preferably, the control unit controls the three arms of the first inverter or the second inverter to allow the precharge operation to be performed.

15 Preferably, the first inverter includes three arms provided correspondingly to the first three-phase motor coil, and the second inverter includes three arms provided correspondingly to the second three-phase motor coil. The precharge operation is performed by using a first motor coil selected from the phase coils of the first three-phase motor coil and a first arm corresponding to the first motor coil and selected from the three arms of the first inverter, or using a second motor coil selected from the phase coils of the second three-phase motor coil and a second arm corresponding to the second motor coil and selected from the three arms of the second inverter.

20 Preferably, the control unit controls the first or second arm to allow the precharge operation to be performed.

25 Preferably, the power output apparatus further includes first and second switches and a resistor element. The first switch is provided between the first neutral point and the power supply. The second switch is provided between the first neutral point and the power supply and in parallel with the first switch. The resistor element is connected between the first neutral point and the first switch. The control unit renders the first and second switches ON and OFF respectively upon start of the precharge operation and renders the first and second switches OFF and ON respectively when it is ascertained that the power supply is connected to the first and second neutral points.

Preferably, after the precharge operation is completed, the control unit displays on a display unit an indication that preparations for driving the power output apparatus are completed.

5 Preferably, the 2Y motor generates electric power from a rotational force from an internal combustion engine.

 Preferably, the power output apparatus further includes an electric motor and a planetary gear. The electric motor is different from the 2Y motor. To the planetary gear, the 2Y motor, the electric motor and the internal combustion engine are connected.

10 Preferably, the power output apparatus further includes a third inverter. The third inverter drives the electric motor. When the control unit drives the first and second inverters to allow the 2Y motor to function as an electric generator, the control unit drives the third inverter to drive the electric motor by electric power generated by the 2Y motor.

15 Preferably, the control unit disconnects the power supply from the first and second neutral points.

 According to the present invention, a motor driving method is a method for driving a 2Y motor coupled to an internal combustion engine of a hybrid vehicle and an electric motor coupled to drive wheels of the hybrid vehicle. The method includes a first step of precharging a capacitor element provided on an input side of first and second inverters controlling energization of first and second three-phase motor coils respectively that are included in the 2Y motor, and a second step of driving the 2Y motor and the electric motor while further charging the capacitor element after the precharging is completed.

25 Preferably, the first step includes a first sub-step of applying a power-supply voltage which is output from a power supply to the capacitor element via the first or second inverter, and a second sub-step of increasing the power-supply voltage to charge the capacitor element.

Preferably, the first sub-step includes a step A of connecting the power supply, via a resistor element, between a first neutral point of the first three-phase motor coil and a second neutral point of the second three-phase motor coil, a step B of ascertaining that the power supply is connected between the first neutral point and the second neutral point, and a step C of directly connecting the power supply between the first neutral point and the second neutral point after the ascertaining is completed.

Preferably, it is determined in the step B that a terminal-to-terminal voltage of the capacitor element is at least the power-supply voltage.

Preferably, the first inverter includes three arms provided correspondingly to the first three-phase motor coil, and the second inverter includes three arms provided correspondingly to the second three-phase motor coil.

In the second sub-step of the motor driving method, the three arms of the first or second inverter are simultaneously driven to increase the power-supply voltage.

Preferably, the first inverter includes three arms provided correspondingly to the first three-phase motor coil, and the second inverter includes three arms provided correspondingly to the second three-phase motor coil.

In the second sub-step of the motor driving method, one arm selected from the three arms of the first or second inverter is driven to increase the power-supply voltage.

Preferably, the motor driving method further includes a third step of displaying on a display unit, after the precharging is completed, an indication that preparations for driving the 2Y motor and/or the electric motor are completed.

Preferably, the second step includes a third sub-step of increasing a power-supply voltage which is output from a power supply to further charge the capacitor element, a fourth sub-step of calculating a first power of the 2Y motor and a second power of the electric motor, a fifth sub-step of determining whether or not the sum of the calculated first power and the calculated second power is equal to zero, and a sixth sub-step of disconnecting, when the sum of the first power and the second power is equal to zero, the power supply from respective neutral points of the first and second

three-phase coils included in the 2Y motor.

Preferably, the second step includes a seventh sub-step of driving the 2Y motor as an electric generator, and an eighth sub-step of driving the electric motor by electric power generated by the 2Y motor.

5 Preferably, the second step includes a ninth sub-step of driving, when the sum of the first power and the second power is unequal to zero, the 2Y motor as an electric motor, by a direct-current voltage from the capacitor element, and a tenth sub-step of driving, when the sum of the first power and the second power is unequal to zero, the 2Y motor as an electric generator while decreasing the direct-current voltage from the
10 capacitor element to charge the power supply.

 According to the present invention, a computer-readable recording medium has a program recorded thereon for allowing a computer to execute drive control of a 2Y motor coupled to an internal combustion engine of a hybrid vehicle and an electric motor coupled to drive wheels of the hybrid vehicle. The computer follows the
15 program to execute a first step of precharging a capacitor element provided on an input side of first and second inverters controlling energization of first and second three-phase motor coils respectively that are included in the 2Y motor, and a second step of driving the 2Y motor and the electric motor while further charging the capacitor element after the precharging is completed.

20 Preferably, the first step includes a first sub-step of applying a power-supply voltage which is output from a power supply to the capacitor element via the first or second inverter and a second sub-step of increasing the power-supply voltage to charge the capacitor element.

 Preferably, the first sub-step includes a step A of connecting the power supply,
25 via a resistor element, between a first neutral point of the first three-phase motor coil and a second neutral point of the second three-phase motor coil, a step B of ascertaining that the power supply is connected between the first neutral point and the second neutral point, and a step C of directly connecting the power supply between the first neutral

point and the second neutral point after the ascertaining is completed.

Preferably, it is determined in the step B that a terminal-to-terminal voltage of the capacitor element is at least the power-supply voltage.

5 Preferably, the first inverter includes three arms provided correspondingly to the first three-phase motor coil, and the second inverter includes three arms provided correspondingly to the second three-phase motor coil.

In the second sub-step of the program, the three arms of the first or second inverter are simultaneously driven to increase the power-supply voltage.

10 Preferably, the first inverter includes three arms provided correspondingly to the first three-phase motor coil, the second inverter includes three arms provided correspondingly to the second three-phase motor coil.

In the second sub-step of the program, one arm selected from the three arms of the first or second inverter is driven to increase the power-supply voltage.

15 Preferably, the computer follows the program to further execute a third step of displaying on a display unit, after the precharging is completed, an indication that preparations for driving the 2Y motor and/or the electric motor are completed.

20 Preferably, the second step includes a third sub-step of increasing a power-supply voltage which is output from a power supply to further charge the capacitor element, a fourth sub-step of calculating a first power of the 2Y motor and a second power of the electric motor, a fifth sub-step of determining whether or not the sum of the calculated first power and the calculated second power is equal to zero, and a sixth sub-step of disconnecting, when the sum of the first power and the second power is equal to zero, the power supply from respective neutral points of the first and second three-phase coils included in the 2Y motor.

25 Preferably, the second step includes a seventh sub-step of driving the 2Y motor as an electric generator, and an eighth sub-step of driving the electric motor by electric power generated by the 2Y motor.

Preferably, the second step includes a ninth sub-step of driving, when the sum

of the first power and the second power is unequal to zero, the 2Y motor as an electric motor, by a direct-current voltage from the capacitor element, and a tenth sub-step of driving, when the sum of the first power and the second power is unequal to zero, the 2Y motor as an electric generator while decreasing the direct-current voltage from the capacitor element to charge the power supply.

According to the present invention, the 2Y motor is driven after the capacitor element, which is provided on the input side of the first and second inverters that drive the 2Y motor, is precharged.

According to the present invention, the power output apparatus can thus be started smoothly.

Moreover, according to the present invention, the power output apparatus operates in such a manner that, after precharging of the capacitor element is completed, the 2Y motor and the electric motor are driven. Then, a high inverter input voltage is supplied to the first and second inverters that drive the 2Y motor and the third inverter that drives the electric motor so that the 2Y motor and the electric motor can be driven with a high output and a high efficiency. In this way, a hybrid vehicle on which this power output apparatus is mounted can be improved in fuel efficiency.

Further, the precharging of the capacitor element increases the inverter input voltage supplied to the first to third inverters and thus vibrations in engine crank can be reduced.

According to the present invention, when the electric power generated by the 2Y motor is used to drive the electric motor, the power supply is disconnected from respective neutral points of the two three-phase coils included in the 2Y motor. Thus, the power generation efficiency of the 2Y motor can be improved and the motor can be operated over a wide range.

Further, the voltage-step-up operation for increasing the voltage of the power supply or the voltage-step-down operation for charging the power supply is carried out by the 2Y motor which does not drive the drive wheels of the hybrid vehicle. Thus, the

electric motor which drives the drive wheels of the hybrid vehicle can exhibit a maximum efficiency.

The foregoing and other objects, features, aspects and advantages of the present invention will become more apparent from the following detailed description of the present invention when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic block diagram of a power output apparatus according to an embodiment of the present invention.

Fig. 2 is an enlarged view of a planetary gear and motors coupled thereto that are shown in Fig. 1.

Fig. 3 is an electrical circuit diagram of a main portion of the power output apparatus shown in Fig. 1.

Fig. 4 is a plan view showing an arrangement of two three-phase coils shown in Fig. 3.

Figs. 5A-5C are circuit diagrams each illustrating a current flow when a potential difference V_{012} between a neutral point M1 of a three-phase coil 10 and a neutral point M2 of a three-phase coil 11 is smaller than a voltage V_b of a DC power supply 30, in terms of leakage inductances of respective U-phase coils of three-phase coils 10 and 11 of a 2Y motor MG1.

Figs. 6A-6C are circuit diagrams each illustrating a current flow when potential difference V_{012} between neutral point M1 of three-phase coil 10 and neutral point M2 of three-phase coil 11 is greater than voltage V_b of DC power supply 30, in terms of leakage inductances of respective U-phase coils of three-phase coils 10 and 11 of 2Y motor MG1.

Figs. 7A and 7B are waveform charts illustrating potentials V_{u1} , V_{v1} and V_{w1} of three-phase coil 10 and potentials V_{u2} , V_{v2} and V_{w2} of three-phase coil 11 when a difference between a potential V_{01} of neutral point M1 of three-phase coil 10 and a potential V_{02} of neutral point M2 of three-phase coil 11 is adjusted to be equal to

voltage V_b of DC power supply 30.

Fig. 8 is a functional block diagram of a control CPU shown in Fig. 3.

Fig. 9 is a functional block diagram of motor control means shown in Fig. 8.

Fig. 10 is a functional block diagram of precharge control means shown in Fig.

5 8.

Fig. 11 is a flowchart illustrating an operation of the power output apparatus shown in Fig. 1.

Fig. 12 is a flowchart illustrating in detail the operation in step S10 shown in Fig. 11.

10 Fig. 13 is a flowchart illustrating in detail the operation in step S20 shown in Fig. 11.

Fig. 14 is a schematic block diagram of a conventional power output apparatus.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

15 An embodiment of the present invention is now described in detail in connection with the drawings. It is noted that like components in the drawings are denoted by like reference characters and description thereof is not repeated here.

20 Fig. 1 is a schematic block diagram of a power output apparatus according to an embodiment of the present invention. Referring to Fig. 1, power output apparatus 100 in this embodiment includes a power transmission gear 111, a drive shaft 112, a differential gear 114, motor generators MG1 and MG2, a planetary gear 120, a power-feed gear 128, a chain belt 129, an engine 150, resolvers 139, 149 and 159, a damper 157 and a controller 180.

25 Engine 150 has a crankshaft 156 connected via damper 157 to planetary gear 120 and motor generators MG1 and MG2. Damper 157 diminishes the amplitude of torsional vibrations of crankshaft 156 of engine 150 and connects crankshaft 156 to planetary gear 120.

Power-feed gear 128 is connected via chain belt 129 to power transmission gear 111. Receiving power from a ring gear (not shown) of planetary gear 120,

power-feed gear 128 transmits the supplied power to power transmission gear 111 via chain belt 129. Power transmission gear 111 then transmits the power to drive wheels via drive shaft 112 and differential gear 114.

Referring to Fig. 2, planetary gear 120 and motor generators MG1 and MG2 are described in detail. Planetary gear 120 includes a sun gear 121 coupled to a hollow sun gear shaft 125 having its axial center through which a carrier shaft 127 passes, a ring gear 122 coupled to a ring gear shaft 126 which is coaxial with carrier shaft 127, a plurality of planetary pinion gears 123 provided between sun gear 121 and ring gear 122 and each revolving around sun gear 121 while rotating on its axis, and a planetary carrier 124 coupled to an end of carrier shaft 127 and rotatably supporting the rotational axis of each planetary pinion gear 123.

In this planetary gear 120, three shafts, namely sun gear shaft 125, ring gear shaft 126 and carrier shaft 127 coupled respectively to sun gear 121, ring gear 122 and planetary carrier 124 serve as power input/output shafts. When power which is input/output to/from two of the three shafts is determined, power to be input/output to/from the remaining one shaft is determined based on the determined power which is input/output to/from the two shafts.

Sun gear shaft 125, ring gear shaft 126 and carrier shaft 127 have respective resolvers 139, 149 and 159 provided thereon for detecting respective rotation angles θ_s , θ_r and θ_c .

To ring gear 122, power-feed gear 128 for taking out power is coupled. Power-feed gear 128 is connected by chain belt 129 to power transmission gear 111 and thus power is transmitted between power-feed gear 128 and power transmission gear 111.

Motor generator MG1 is constructed as a synchronous motor-generator and includes a rotor 132 having a plurality of permanent magnets 135 on its outer peripheral surface and a stator 133 around which a three-phase coil 134 is wound to generate a revolving magnetic field. Three-phase coil 134 includes two three-phase coils as

described hereinlater.

Rotor 132 is coupled to sun gear shaft 125 which is coupled to sun gear 121 of planetary gear 120. Stator 133 is formed by stacking thin non-directional electromagnetic steel plates and is fixed to a case 119. Motor generator MG1 operates to serve as an electric motor which rotationally drives rotor 132 through an interaction between a magnetic field generated by permanent magnets 135 and the magnetic field generated by three-phase coil 134, or as an electric generator which generates an electromotive force on both ends of three-phase coil 134 through an interaction between the magnetic field generated by permanent magnets 135 and rotations of rotor 132.

Motor generator MG2 includes a rotor 142 having a plurality of permanent magnets 145 on its outer peripheral surface and a stator 143 around which a three-phase coil 144 is wound to generate a revolving magnetic field. Rotor 142 is coupled to ring gear shaft 126 which is coupled to ring gear 122 of planetary gear 120, and stator 143 is fixed to case 119. Stator 143 is also formed by stacking thin non-directional electromagnetic steel plates. This motor generator MG2 operates, like motor generator MG1, to serve as an electric motor or electric generator.

Referring again to Fig. 1, controller 180 receives a signal STON from a start key 186, rotation angle θ_s of sun gear shaft 125 from resolver 139, rotation angle θ_r of ring gear shaft 126 from resolver 149, rotation angle θ_c of carrier shaft 127 from resolver 159, an accelerator pedal position (step-on amount of the accelerator pedal) AP from an accelerator pedal position sensor 164a, a brake pedal position (step-on amount of the brake pedal) BP from a brake pedal position sensor 165a, a shift position SP from a shift position sensor 185, motor currents MCRT11 and MCRT12 from two current sensors (not shown) attached to motor generator MG1 and a motor current MCRT2 from a current sensor (not shown) attached to motor generator MG2. Signal STON indicates that power output apparatus 100 is made ON.

According to each of the supplied signals, controller 180 controls current to be flown through three-phase coils 134 and 144 of motor generators MG1 and MG2 and

thereby drives motor generators MG1 and MG2.

Fig. 3 is an electrical circuit diagram of a main portion of power output apparatus 100. Referring to Fig. 3, power output apparatus 100 includes motor generators MG1 and MG2, current sensors 12-14 and 31, a DC power supply 30, voltage sensors 32 and 51, a relay 40, a capacitor 50, inverters 181-183, a control CPU (Central Processing Unit) 184, and a display unit 190.

Inverters 181-183 and control CPU 184 constitute controller 180 shown in Fig. 1.

Motor generator MG1 includes two three-phase coils 10 and 11. Two three-phase coils 10 and 11 constitute three-phase coil 134 shown in Fig. 2. Namely, motor generator MG1 is a double-winding motor having Y-connected two three-phase coils 10 and 11 (called "2Y motor" in some cases).

DC power supply 30 is connected, via relay 40, between neutral point M1 of three-phase coil 10 and neutral point M2 of three-phase coil 11.

Inverter 181 includes a U-phase arm 15, a V-phase arm 16 and a W-phase arm 17. U-phase arm 15, V-phase arm 16 and W-phase arm 17 are provided in parallel between a power-supply line 1 and a ground line 2.

U-phase arm 15 is constituted of NPN transistors Q1 and Q2 connected in series between power-supply line 1 and ground line 2. V-phase arm 16 is constituted of NPN transistors Q3 and Q4 connected in series between power-supply line 1 and ground line 2. W-phase arm 17 is constituted of NPN transistors Q5 and Q6 connected in series between power-supply line 1 and ground line 2.

NPN transistors Q1, Q3 and Q5 have respective collectors connected to power-supply line 1 and respective emitters connected to respective collectors of NPN transistors Q2, Q4 and Q6. Respective emitters of NPN transistors Q2, Q4 and Q6 are connected to ground line 2. Diodes D1-D6 each flowing current from the emitter to the collector are connected respectively between respective emitters and collectors of NPN transistors Q1-Q6.

Inverter 182 includes a U-phase arm 18, a V-phase arm 19 and a W-phase arm 20. U-phase arm 18, V-phase arm 19 and W-phase arm 20 are provided in parallel between power-supply line 1 and ground line 2.

5 U-phase arm 18 is constituted of NPN transistors Q7 and Q8 connected in series between power-supply line 1 and ground line 2. V-phase arm 19 is constituted of NPN transistors Q9 and Q10 connected in series between power-supply line 1 and ground line 2. W-phase arm 20 is constituted of NPN transistors Q11 and Q12 connected in series between power-supply line 1 and ground line 2.

10 NPN transistors Q7, Q9 and Q11 have respective collectors connected to power-supply line 1 and respective emitters connected to respective collectors of NPN transistors Q8, Q10 and Q12. NPN transistors Q8, Q10 and Q12 have respective emitters connected to ground line 2. Diodes D7-D12 each flowing current from the emitter to the collector are connected respectively between respective emitters and collectors of NPN transistors Q7-Q12.

15 Respective intermediate points of the phase arms of inverter 181 are connected respectively to respective ends of the phase coils of three-phase coil 10 of motor generator MG1, and respective intermediate points of the phase arms of inverter 182 are connected respectively to respective ends of the phase coils of three-phase coil 11 of motor generator MG1. In other words, respective one-ends of the U-, V- and
20 W-phase coils of three-phase coil 10 are commonly connected to neutral point M1, while the other end of the U-phase coil is connected to the intermediate point between NPN transistors Q1 and Q2, the other end of the V-phase coil is connected to the intermediate point between NPN transistors Q3 and Q4 and the other end of the
25 W-phase coil is connected to the intermediate point between NPN transistors Q5 and Q6. Further, respective one-ends of the U-, V- and W-phase coils of three-phase coil 11 are commonly connected to neutral point M2, while the other end of the U-phase coil is connected to the intermediate point between NPN transistors Q7 and Q8, the other end of the V-phase coil is connected to the intermediate point between NPN transistors

Q9 and Q10 and the other end of the W-phase coil is connected to the intermediate point between NPN transistors Q11 and Q12.

Inverter 183 includes a U-phase arm 21, a V-phase arm 22 and a W-phase arm 23. U-phase arm 21, V-phase arm 22 and W-phase arm 23 are provided in parallel
5 between power-supply line 1 and ground line 2.

U-phase arm 21 is constituted of NPN transistors Q13 and Q14 connected in series between power-supply line 1 and ground line 2. V-phase arm 22 is constituted of NPN transistors Q15 and Q16 connected in series between power-supply line 1 and ground line 2. W-phase arm 23 is constituted of NPN transistors Q17 and Q18
10 connected in series between power-supply line 1 and ground line 2.

NPN transistors Q13, Q15 and Q17 have respective collectors connected to power-supply line 1 and respective emitters connected to respective collectors of NPN transistors Q14, Q16 and Q18. Respective emitters of NPN transistors Q14, Q16 and Q18 are connected to ground line 2. Diodes D13-D18 each flowing current from the
15 emitter to the collector are connected respectively between respective emitters and collectors of NPN transistors Q13-Q18.

Respective intermediate points of the phase arms of inverter 183 are connected respectively to respective ends of the phase coils of motor generator MG2. In other words, motor generator MG2 is a three-phase permanent-magnet motor in which
20 respective one-ends of the U-, V- and W-phase coils are commonly connected to the neutral point, while the other end of the U-phase coil is connected to the intermediate point between NPN transistors Q13 and Q14, the other end of the V-phase coil is connected to the intermediate point between NPN transistors Q15 and Q16 and the other end of the W-phase coil is connected to the intermediate point between NPN
25 transistors Q17 and Q18.

Capacitor 50 is connected between power-supply line 1 and ground line 2 and in parallel with inverters 181-183.

Current sensor 12 detects motor current MCRT11 flowing through three-phase

coil 10 of motor generator MG1 to output detected motor current MCRT11 to control CPU 184. Current sensor 13 detects motor current MCRT12 flowing through three-phase coil 11 of motor generator MG1 to output detected motor current MCRT12 to control CPU 184. Current sensor 14 detects motor current MCRT2 flowing
5 through the phase coils of motor generator MG2 to output detected motor current MCRT2 to control CPU 184.

DC power supply 30 is constructed of secondary or rechargeable cell(s), for example, of nickel hydride or lithium ion. Current sensor 31 detects a battery current BCRT which is input/output to/from DC power supply 30 to output detected battery
10 current BCRT to control CPU 184. Current sensor 32 detects a DC voltage Vb which is output from DC power supply 30 to output detected DC voltage Vb to control CPU 184.

Relay 40 includes system relays SMR1-SMR3 and a resistor R1. System relay SMR1 and resistor R1 are connected in series between neutral point M1 of three-phase
15 coil 10 and the positive terminal of DC power supply 30. System relay SMR2 is connected between neutral point M1 of three-phase coil 10 and the positive terminal of DC power supply 30 and in parallel with system relay SMR1 and resistor R1. System relay SMR3 is connected between neutral point M2 of three-phase coil 11 and the negative terminal of DC power supply 30.

20 System relays SMR1-SMR3 are each made ON/OFF by a signal SE from control CPU 184. Specifically, system relays SMR1-SMR3 are each made ON by signal SE at an H (logical high) level from control CPU 184 and is made OFF by signal SE at an L (logical low) level from control CPU 184.

Capacitor 50 smoothes a DC voltage applied between power-supply line 1 and
25 ground line 2 to supply the smoothed DC voltage to inverters 181-183. Voltage sensor 51 detects a terminal-to-terminal voltage Vc of capacitor 50 to output detected voltage Vc to control CPU 184.

Inverter 181 increases DC voltage Vb output from DC power supply 30 to

precharge capacitor 50 according to a signal PWMPC1 from control CPU 184.

Inverter 182 increases DC voltage V_b output from DC power supply 30 to precharge capacitor 50 according to a signal PWMPC2 from control CPU 184. Accordingly, terminal-to-terminal voltage V_c of capacitor 50 is increased to a predetermined voltage so that preparations are made for driving motor generators MG1 and MG2.

Inverter 181 converts the DC voltage supplied from capacitor 50 into an AC voltage according to a signal PWMI1 from control CPU 184 to apply the AC voltage to the phase coils of three-phase coil 10. Inverter 182 converts the DC voltage supplied from capacitor 50 into an AC voltage according to a signal PWMI2 from control CPU 184 to apply the AC voltage to the phase coils of three-phase coil 11. Inverters 181 and 182 thus drive motor generator MG1. When DC power supply 30 is connected by relay 40 between neutral points M1 and M2, inverters 181 and 182 respectively supply the AC current superimposed on the DC current from DC power supply 30 to the phase coils of three-phase coils 10 and 11, according to signals PWMI1 and PWMI2 respectively.

Inverter 181 converts an AC voltage generated by three-phase coil 10 into a DC voltage according to a signal PWMC1 from control CPU 184 to supply the resultant DC voltage to capacitor 50. Inverter 182 converts an AC voltage generated by three-phase coil 11 into a DC voltage according to a signal PWMC2 from control CPU 184 to supply the resultant DC voltage to capacitor 50. When DC power supply 30 is connected by relay 40 between neutral points M1 and M2, inverters 181 and 182 decrease the DC voltage from capacitor 50 to charge DC power supply 30 with the decreased DC voltage according to signals PWMC1 and PWMC2 respectively.

Inverter 183 converts the DC voltage from capacitor 50 into an AC voltage according to a signal PWMI3 from control CPU 184 to drive motor generator MG2. Further, inverter 183 converts, according to a signal PWMC3 from control CPU 184, an AC voltage generated by motor generator MG2 into a DC voltage to supply the resultant DC voltage to capacitor 50.

Control CPU 184 generates a signal SE1 (a kind of signal SE) at H level for rendering system relays SMR1 and SMR3 ON, according to signal STON from start key 186 that indicates that the start key of a hybrid vehicle on which power output apparatus 100 is mounted is made ON, and outputs the generated signal SE1 at H level to relay 40.
5 DC power supply 30 is thus connected via resistor R1 between neutral points M1 and M2. The DC current which is output from DC power supply is supplied to capacitor 50 via the U-, V- and W-phase coils of three-phase coil 10 and diodes D1, D3 and D5 of inverter 181.

Then, control CPU 184 determines whether or not voltage Vc from voltage
10 sensor 51 is equal to or higher than DC voltage Vb. If control CPU 184 determines that voltage Vc is equal to or higher than DC voltage Vb, control CPU 184 generates a signal SE2 (a kind of signal SE, including a signal SE21 at H level for system relay SMR2 and a signal SE22 at L level for system relay SMR1) for rendering system relay SMR2 ON and then rendering system relay SMR1 OFF, and outputs the generated
15 signal to relay 40.

According to DC voltage Vb from voltage sensor 32 and voltage Vc from voltage sensor 51, control CPU 184 generates a signal PWMPC1 or PWMPC2 for increasing DC voltage Vb output from DC power supply 30 by a method described hereinbelow and outputs the generated signal PWMPC1 or PWMPC2 to inverter 181 or
20 182. Accordingly, DC voltage Vb output from DC power supply 30 is increased to be supplied to capacitor 50 which is accordingly precharged to a predetermined voltage.

In this way, control CPU 184 receives signal STON from start key 186 to control inverter 181 and 182 and thereby allow capacitor 50 to be precharged to a predetermined voltage.

25 Control CPU 184 further determines whether or not voltage Vc from voltage sensor 51 is a predetermined voltage. If voltage Vc equals to the predetermined voltage or higher, control CPU 184 generates a signal DPL indicating that capacitor 50 is precharged and supplies the generated signal to display unit 190. If voltage Vc from

voltage sensor 51 is lower than the predetermined voltage, control CPU 184 generates a signal ERR for showing an error indication on display unit 190 to output the generated signal to display unit 190.

5 Control CPU 184 calculates, based on accelerator pedal position AP from accelerator pedal position sensor 164a, brake pedal position BP from brake pedal position sensor 165a and shift position SP from shift position sensor 185, an engine command power, a generator command torque (motor generator MG1 command torque) TR1 and a motor command torque (motor generator MG2 command torque) TR2.

10 Control CPU 184 further calculates the number of revolutions of the generator (motor generator MG1) according to rotation angle θ_s from resolver 139, and multiplies the calculated generator command torque TR1 by the number of revolutions to calculate a generator power P_g . Control CPU 184 calculates the number of revolutions of the motor (motor generator MG2) according to rotation angle θ_r from resolver 149, and
15 multiplies the calculated generator command torque TR2 by the number of revolutions to calculate a motor power P_m . Control CPU 184 then determines whether the sum of motor power P_m and generator power P_g , namely $P_m + P_g$, is zero or not. If the sum $P_m + P_g$ is zero, control CPU 184 disconnects DC power supply 30 from neutral points M1 and M2 to drive motor generators MG1 and MG2. If the sum $P_m + P_g$ is not zero,
20 control CPU 184 drives motor generators MG1 and MG2 with DC power supply 30 connected to neutral points M1 and M2.

Control CPU 184 calculates, based on the calculated generator command torque TR1, current command values I_{d1}^* and I_{q1}^* of motor generator MG1 as well as a capacitor voltage command value V_c^* of capacitor 50. Further, control CPU 184
25 calculates, based on the calculated motor command torque TR2, current command values I_{d2}^* and I_{q2}^* of motor generator MG2.

Then, control CPU 184 generates signals PWMI1, PWMI2, PWMC1 and PWMC2, according to motor currents MCRT11 and MCRT12 from current sensors 12

and 13, battery current BCRT from current sensor 31, rotation angle θ_s from resolver 139 mounted on sun gear shaft 125 to which the rotational shaft of motor generator MG1 is coupled, the calculated current command values I_{d1}^* and I_{q1}^* and capacitor voltage command value V_c^* , outputs the generated signals PWMI1 and PWMC1 to inverter 181 and outputs generated signals PWMI2 and PWMC2 to inverter 182.

Further, control CPU 184 generates signals PWMI3 and PWMC3 according to motor current MCRT2 from current sensor 14, rotation angle θ_r from resolver 149 mounted on ring gear shaft 126 to which the rotational shaft of motor generator MG2 is coupled and the calculated current command values I_{d2}^* and I_{q2}^* , and outputs the generated signals PWMI3 and PWMC3 to inverter 183.

Display unit 190 displays "READY" which indicates that preparations for driving motor generators MG1 and MG2 have been done, according to signal DPL from control CPU 184. Display unit 190 further displays "ERROR" indicating that preparations for driving motor generators MG1 and MG2 are not made, according to signal ERR from control CPU 184. Specifically, display unit 190 is a meter panel.

Fig. 4 is a plan view showing an arrangement of two three-phase coils 10 and 11 of motor generator MG1. In general, motor generator MG1 includes three-phase coil 10 and three-phase coil 11 displaced by an angle α in the rotational direction with respect to three-phase coil 10. In other words, motor generator MG1 may be regarded as a six-phase motor.

In this embodiment, angle α is supposed to be zero and descriptions will be given accordingly. In other words, two three-phase coils 10 and 11 have windings that are in phase with each other. Then, inverters 181 and 182 may supply AC currents that are in phase with each other to three-phase coils 10 and 11 respectively. Specifically, the AC current supplied to the U-, V- and W-phase coils of three-phase coil 10 is in phase with the AC current supplied to the U-, V- and W-phase coils of three-phase coil 11.

Referring to Figs. 5A-5C and Figs. 6A-6C, a description is given below of an

operational principle of motor generator MG1 and inverters 181 and 182 when DC power supply 30 is connected between neutral points M1 and M2.

5 Figs. 5A-5C each show a circuit diagram which illustrates a current flow when a potential difference V_{012} between neutral point M1 of three-phase coil 10 and neutral point M2 of three-phase coil 11 is smaller than voltage V_b of DC power supply 30, in terms of leakage inductances of respective U-phase coils of three-phase coils 10 and 11 of 2Y motor MG1.

10 It is supposed here that, under the condition that potential difference V_{012} between respective neutral points M1 and M2 of three-phase coils 10 and 11 is smaller than voltage V_b of DC power supply 30, NPN transistor Q2 of inverter 181 is in an ON state or NPN transistor Q7 of inverter 182 is in an ON state.

15 In this case, a short circuit as indicated by the solid lines with arrows in Fig. 5A or 5B is formed so that respective U-phase coils of three-phase coils 10 and 11 of 2Y motor MG1 function as reactors. Starting from this state, NPN transistor Q2 of inverter 181 that is in the ON state is turned off or NPN transistor Q7 of inverter 182 that is in the ON state is turned off so that the energy stored in respective U-phase coils of three-phase coils 10 and 11 that function as reactors is stored in capacitor 50 by a charging circuit represented by the solid lines with arrows in Fig. 5C. Accordingly, this circuit can be regarded as a capacitor-charging circuit which increases DC voltage V_b of DC power supply 30 to charge capacitor 50 with the increased DC voltage.

20 Since the level to which the voltage is to be increased can freely be set according to the period in which NPN transistor Q2 or Q7 is in the ON state, terminal-to-terminal voltage V_c of capacitor 50 can be set to an arbitrary voltage which is higher than voltage V_b of DC power supply 30.

25 Similarly to the U-phase coils, V- and W-phase coils of three-phase coils 10 and 11 of 2Y motor MG1 can be regarded as capacitor-charging circuits. Then, voltage V_b of DC power supply 30 can be increased so as to charge capacitor 50 by setting potential difference V_{012} between respective neutral points M1 and M2 of three

phase coils 10 and 11 to be smaller than voltage V_b of DC power supply 30 and turning on/off NPN transistors Q2, Q4 and Q6 of inverter 181 or NPN transistors Q7, Q9 and Q11 of inverter 182.

5 Figs. 6A-6C each show a circuit diagram which illustrates a current flow when potential difference V_{012} between respective neutral points M1 and M2 of three-phase coils 10 and 11 is greater than voltage V_b of DC power supply 30, in terms of leakage inductances of respective U-phase coils of three-phase coils 10 and 11 of 2Y motor MG1.

10 It is supposed here that, under the condition that potential difference V_{012} between respective neutral points M1 and M2 of three-phase coils 10 and 11 is greater than voltage V_b of DC power supply 30, NPN transistor Q1 of inverter 181 is turned on, NPN transistor Q2 thereof is turned off, NPN transistor Q7 of inverter 182 is turned off and NPN transistor Q8 thereof is turned on. In this case, a charging circuit represented by the solid lines with arrows as shown in Fig. 6A is formed so that DC power supply 30
15 is charged with terminal-to-terminal voltage V_c of capacitor 50. At this time, respective U-phase coils of three-phase coils 10 and 11 of 2Y motor MG1 function as reactors as described above. Starting from this state, NPN transistor Q1 of inverter 181 or NPN transistor Q8 of inverter 182 is turned off so that the energy stored in respective U-phase coils of three-phase coils 10 and 11 that function as reactors is used
20 to charge DC power supply 30 by a charging circuit represented by the solid lines with arrows as shown in Fig. 6B or 6C.

Accordingly, this circuit can be regarded as a DC power supply charging circuit that stores, in DC power supply 30, the energy stored in capacitor 50. Similarly to the U-phase coils, V- and W-phase coils of three-phase coils 10 and 11 of 2Y motor MG1
25 can be regarded as DC power supply charging circuits. Then, DC power supply 30 can be charged with the energy stored in capacitor 50 by setting potential difference V_{012} between respective neutral points M1 and M2 of three-phase coils 10 and 11 to be greater than voltage V_b of DC power supply 30 and turning on/off NPN transistors

Q1-Q6 of inverter 181 or NPN transistors Q7-Q12 of inverter 182.

As discussed above, in power output apparatus 100, capacitor 50 can be charged by DC power supply 30 or DC power supply 30 can be charged by capacitor 50. Thus, terminal-to-terminal voltage V_c of capacitor 50 can be set to a predetermined value.

When a potential difference is generated between the terminals of capacitor 50, capacitor 50 functions as a DC power supply connected between power-supply line 1 and ground line 2 to which inverters 181 and 182 are connected, so that terminal-to-terminal voltage V_c of capacitor 50 is now an inverter input voltage V_i . Then, through switching control of NPN transistors Q1-Q6 and Q7-Q12 of inverters 181 and 182, drive control of 2Y motor MG1 can be done.

In this case, potentials V_{u1} , V_{v1} and V_{w1} of respective phases of three-phase AC current to be applied to three-phase coil 10 can be set freely within a range of inverter input voltage V_i by switching control of NPN transistors Q1-Q6 of inverter 181, and potentials V_{u2} , V_{v2} and V_{w2} of respective phases of three-phase AC current to be applied to three-phase coil 11 can be set freely within the range of inverter input voltage V_i by switching control of NPN transistors Q7-Q12 of inverter 182. Accordingly, a potential V_{01} on neutral point M1 of three-phase coil 10 of 2Y motor MG1 and a potential V_{02} on neutral point M2 of three-phase coil 11 can freely be controlled.

Figs. 7A and 7B respectively show waveform charts for potentials V_{u1} , V_{v1} and V_{w1} of three-phase coil 10 (Fig. 7A) and potentials V_{u2} , V_{v2} and V_{w2} of three-phase coil 11 (Fig. 7B) when a difference between potential V_{01} on neutral point M1 of three-phase coil 10 and potential V_{02} on neutral point M2 of three-phase coil 11 is adjusted to be equal to voltage V_b of DC power supply 30. In Figs. 7A and 7B, V_x represents the median ($V_i/2$) of inverter input voltage V_i . Then, control can be done in such a manner that potential difference V_{012} between respective neutral points M1 and M2 of three-phase coils 10 and 11 of 2Y motor MG1 is lower than voltage V_b of DC power supply 30 so as to charge capacitor 50, or, on the contrary, control can be done

in such a manner that potential difference V012 between respective neutral points M1 and M2 of three-phase coils 10 and 11 is larger than voltage Vb of DC power supply 30 so as to charge DC power supply 30. Further, a charging current for capacitor 50 or a charging current for DC power supply 30 can be controlled by increasing/decreasing
5 potential difference V012 between respective neutral points M1 and M2 of three-phase coils 10 and 11.

Fig. 8 is a functional block diagram of control CPU 184 shown in Fig. 3. Referring to Fig. 8, control CPU 184 includes motor control means 184A and precharge control means 184B.

10 Receiving signal DPL from precharge control means 184B, motor control means 184A generates signals PWMI1-PWMI3 and signals PWMC1-PWMC3 by a method which is described hereinbelow, based on rotation angle θ_s from resolver 139, rotation angle θ_r from resolver 149, motor current MCRT11 from current sensor 12, motor current MCRT12 from current sensor 13, motor current MCRT2 from current
15 sensor 14, battery current BCRT from current sensor 31 and voltage Vc from voltage sensor 51. Motor control means 184A then outputs the generated signals PWMI1 and PWMC1 to inverter 181, outputs the generated signals PWMI2 and PWMC2 to inverter 182 and outputs the generated signals PWMI3 and PWMC3 to inverter 183. If motor control means 184A receives signal ERR from precharge control means 184B, motor
20 control means 184A does not generate signals PWMI1-PWMI3 and signals PWMC1-PWMC3.

Receiving signal STON from start key 186, precharge control means 184B generates signal SE1 at H level for rendering system relays SMR1 and SMR3 ON and outputs the generated signal to relay 40. Precharge control means 184B then
25 determines whether or not voltage Vc from voltage sensor 51 is equal to or higher than voltage Vb from voltage sensor 32. If precharge control means 184B determines that voltage Vc is equal to or higher than voltage Vb, precharge control means 184B generates signal SE2 for rendering system relay SMR2 ON and then rendering system

relay SMR1 OFF and outputs the generated signal to relay 40.

Accordingly, precharge control means 184B generates signal PWMPC1 or signal PWMPC2 for increasing voltage V_b to a predetermined voltage and thereby precharge capacitor 50, and outputs the generated signal PWMPC1 or signal PWMPC2 to inverter 181 or 182.

Then, precharge control means 184B generates, when voltage V_c from voltage sensor 51 reaches the predetermined voltage, signal DPL indicating that capacitor 50 is precharged, and outputs the generated signal DPL to motor control means 184A and display unit 190. Precharge control means 184B generates, if voltage V_c is not equal to or higher than voltage V_b , signal ERR indicating that capacitor 50 is not precharged and outputs the generated signal to motor control means 184A and display unit 190.

Fig. 9 shows a functional block diagram of motor control means 184A shown in Fig. 8. Referring to Fig. 9, motor control means 184A includes a current converting unit 1841, subtracters 1842 and 1852, PI control units 1843, 1853 and 1855, adders 1844 and 1846, a converting unit 1845, a PWM calculation unit 1847, a rotational speed calculation unit 1849, a speed-electromotive-force predictive calculation unit 1850, a battery-current predictive calculation unit 1851, and an adder/subtractor 1854.

Motor control means 184A generates signals PWMI1-PWMI3 and signals PWMC1-PWMC3 as described above. A description is now given below of a function of motor control means 184A which generates signals PWMI1 and PWMI2 and signals PWMC1 and PWMC2. According to signal DPL from precharge control means 184B, current converting unit 1841 performs three-phase to two-phase conversion on motor currents MCRT11 and MCRT12 detected respectively by current sensors 12 and 13 by using rotation angle θ_s detected by resolver 139. Specifically, current converting unit 1841 uses rotation angle θ_s to convert three-phase motor currents MCRT11 and MCRT12 flowing through the phase coils of three-phase coils 10 and 11 of 2Y motor MG1 into values I_d and I_q of currents flowing through d- and q-axes, and outputs the resultant values to subtracter 1842.

Subtractor 1842 subtracts, from current command values I_{d1}^* and I_{q1}^* that have been calculated by control CPU 184 as a part of command values regarding drive of 2Y motor MG1, current values I_d and I_q supplied from current converting unit 1841 so as to determine deviations ΔI_d and ΔI_q . PI control unit 1843 calculates a control amount for adjusting the motor current, by using a PI gain for deviations ΔI_d and ΔI_q .

Rotational speed calculation unit 1849 calculates a rotational speed of 2Y motor MG1 based on rotation angle θ_s from resolver 139 and outputs the calculated rotational speed to speed-electromotive-force predictive calculation unit 1850 and to battery-current predictive calculation unit 1851. Speed-electromotive-force predictive calculation unit 1850 calculates a predictive value of the speed electromotive force based on the rotational speed from rotational speed calculation unit 1849.

Adder 1844 adds the control amount for adjusting the motor current that is supplied from PI control unit 1843 to the predictive value of the speed electromotive force that is supplied from speed-electromotive-force predictive calculation unit 1850 to calculate voltage control amounts V_d and V_q . Using rotation angle θ_s from resolver 139, converting unit 1845 performs two-phase to three-phase conversion on voltage control amounts V_d and V_q from adder 1844. Specifically, converting unit 1845 uses rotation angle θ_s to convert control amounts V_d and V_q for the voltages to be applied to the d-axis and the q-axis into control amounts for voltages to be applied to three phase coils (U-, V- and W-phase coils) of three-phase coils 10 and 11 of 2Y motor MG1.

Subtractor 1852 subtracts, from capacitor voltage command value V_{c}^* which is a command value for the terminal-to-terminal voltage of capacitor 50 and has been calculated by control CPU 184, terminal-to-terminal voltage V_c of capacitor 50 that is detected by voltage sensor 51 so as to calculate a deviation ΔV_c . PI control unit 1853 uses the PI gain for deviation ΔV_c from subtractor 1852 to calculate a control amount of the battery current for adjusting the capacitor voltage. Battery-current predictive calculation unit 1851 calculates a predictive value of the battery current based on the

rotational speed calculated by rotational speed calculation unit 1849 and current command values I_{d1}^* and I_{q1}^* , and outputs the calculated predictive value of the battery current to adder/subtractor 1854.

5 Adder/subtractor 1854 adds the predictive value of the battery current from battery-current predictive calculation unit 1851 to the battery current control amount from PI control unit 1853. Then, adder/subtractor 1854 receives, from current sensor 31, a DC current which is input/output to/from DC power supply 30, namely battery current BCRT, subtracts battery current BCRT from the sum which has been calculated, and then outputs the result of the subtraction to PI control unit 1855. PI control unit 10 1855 uses the PI gain for the output from adder/subtractor 1854 to set potential difference V012 between neutral points M1 and M2 of three-phase coils 10 and 11 for adjusting the battery current.

Adder 1846 adds, to phase potentials V_{u1} , V_{v1} , V_{w1} , V_{u2} , V_{v2} and V_{w2} that are output from converting unit 1845, potential difference V012 which is output from PI 15 control unit 1855, and then outputs the resultant sum to PWM calculation unit 1847. PWM calculation unit 1847 generates signals PWMI1, PWMI2, PWMC1 and PWMC2 based on the output from adder 1846. To phase potentials V_{u1} , V_{v1} , V_{w1} , V_{u2} , V_{v2} and V_{w2} obtained from converting unit 1845, potential difference V012 between neutral points M1 and M2 that is calculated by subtracter 1852, PI control unit 1853, 20 battery-current predictive calculation unit 1851, adder/subtractor 1854 and PI control unit 1855 is added to calculate PWM signals (signals PWMI1 and PWMI2 and signals PWMC1 and PWMC2). Accordingly, the three-phase AC currents applied to three-phase coils 10 and 11 can have the waveforms with offsets from median V_x as shown in Figs. 7A and 7B, so that a current can be flown to DC power supply 30 to 25 maintain voltage V_c of capacitor 50 that functions as inverter input voltage V_i at command value V_c^* .

A description is given below of a function of motor control means 184A which generates signals PWMI3 and PWMC3. Signals PWMI3 and PWMC3 are generated

by current converting unit 1841, subtracter 1842, PI control unit 1843, adder 1844, converting unit 1845, adder 1846, PWM calculation unit 1847, rotational speed calculation unit 1849 and speed-electromotive-force predictive calculation unit 1850 as described above. Current converting unit 1841 uses rotation angle θ_r from resolver 149 to perform three-phase to two-phase conversion on motor current MCRT2.

Converting unit 1845 uses rotation angle θ_r from resolver 149 to perform two-phase to three-phase conversion. Rotational speed calculation unit 1849 uses rotation angle θ_r from resolver 149 to calculate the rotational speed. Further, adder 1846 adds nothing to phase potentials Vu3, Vv3 and Vw3 (voltage to be applied to each phase coil of motor generator MG2) from converting unit 1845 to output the potentials as they are to PWM calculation unit 1847. In this way, PWM calculation unit 1847 generates signals PWMI3 and PWMC3.

It is noted here that current converting unit 1841 does not perform the three-phase to two-phase conversion on motor currents MCRT11, MCRT12 and MCRT2 when current converting unit 1841 receives signal ERR from precharge control means 184B.

Fig. 10 is a functional block diagram of precharge control means 184B shown in Fig. 8. Referring to Fig. 10, precharge control means 184B includes a control unit 1861, a voltage command setting unit 1862, a feedback voltage command calculation unit 1863 and a duty ratio converting unit 1864.

Receiving signal STON from start key 186, control unit 1861 generates signal SE1 at H level for rendering system relays SMR1 and SMR3 ON and outputs the generated signal to relay 40. Control unit 1861 then determines whether or not voltage Vc from voltage sensor 51 is equal to or higher than voltage Vb from voltage sensor 32. If control unit 1861 determines that voltage Vc is not equal to or higher than voltage Vb, control unit 1861 generates signal ERR for displaying an error indication on display unit 190 and outputs the generated signal to motor control means 184A and display unit 190.

If control unit 1861 determines that voltage Vc is equal to or higher than

voltage V_b , control unit 1861 generates signal SE2 for rendering system relay SMR2 ON and thereafter rendering system relay SMR1 OFF as well as signal STAT for starting precharging of capacitor 50. Control unit 1861 then outputs the generated signal SE2 to relay 40 and the generated signal STAT to voltage command setting unit 1862.

Further, control unit 1861 determines, after it outputs signal STAT to voltage command setting unit 1862, whether or not voltage V_c from voltage sensor 51 is equal to or higher than voltage command V_{dc_com} . If control unit 1861 determines that voltage V_c is lower than V_{dc_com} , control unit 1861 generates signal ERR and outputs the generated signal to motor control means 184A and display unit 190.

If control unit 1861 determines that voltage V_c is equal to or higher than voltage command V_{dc_com} , control unit 1861 generates signal DPL which indicates that preparations for driving motor generators MG1 and MG2 are made as well as signal STP for stopping the precharging of capacitor 50. Control unit 1861 then outputs the generated signal DPL to motor control means 184A and display unit 190 and the generated signal STP to voltage command setting unit 1862.

Voltage command setting unit 1862 holds, in advance, voltage command V_{dc_com} which is a target value of terminal-to-terminal voltage V_c of capacitor 50 when capacitor 50 is precharged. Receiving signal STAT from control unit 1861, voltage command setting unit 1862 outputs voltage command V_{dc_com} which is held in advance to control unit 1861 and feedback voltage command calculation unit 1863.

Receiving signal STP from control unit 1861, voltage command setting unit 1862 outputs a voltage command $V_{dc_com_0}$ of 0V to feedback voltage command calculation unit 1863.

Based on voltage V_c from voltage sensor 51 and voltage command V_{dc_com} (including $V_{dc_com_0}$) from voltage command setting unit 1862, feedback voltage command calculation unit 1863 calculates a feedback voltage command and outputs the calculated feedback voltage command to duty ratio converting unit 1864.

Based on voltage V_b from voltage sensor 32 and the feedback voltage command from feedback voltage command calculation unit 1863, duty ratio converting unit 1864 calculates a duty ratio for setting voltage V_c from voltage sensor 51 to the feedback voltage command from feedback voltage command calculation unit 1863 and, based on the calculated duty ratio, generates signal PWMPC1 or PWMPC2 for turning on/off NPN transistors Q1-Q6 or Q7-Q12 of inverter 181 or 182. Then, duty ratio converting unit 1864 outputs the generated signal PWMPC1 or PWMPC2 to NPN transistors Q1-Q6 or Q7-Q12 of inverter 181 or 182.

If inverter 181 or 182 is used as a switching circuit of a voltage step-up converter, the ON-duty of NPN transistors Q2, Q4 and Q6 located on the lower side of inverter 181 or NPN transistors Q7, Q9 and Q11 located on the upper side of inverter 182 is increased to increase the power stored in three-phase coils 10 and 11, so that an output of a higher voltage can be obtained.

Fig. 11 is a flowchart illustrating an operation of power output apparatus 100 shown in Fig. 1. Referring to Fig. 11, upon the start of a series of operations, precharge control means 184B of control CPU 184 generates signal PWMPC1 or PWMPC2 according to signal STON from start key 186, and outputs the generated signal PWMPC1 or PWMPC2 to inverter 181 or 182.

According to signal PWMPC1 or PWMPC2, inverter 181 or 182 switches the DC current flowing from DC power supply 30 through three-phase coil 10 or 11 to store electric power in three-phase coil 10 or 11. Inverter 181 or 182 supplies a DC voltage corresponding to the electric power stored in three-phase coil 10 or 11 to capacitor 50. Capacitor 50 is thus precharged to a predetermined voltage (step S10).

When the precharging of capacitor 50 is completed, precharge control means 184B outputs signal DPL which indicates that preparations for driving motor generators MG1 and MG2 (motor and generator) are made to motor control means 184A and display unit 190. According to signal DPL, display unit 190 displays "READY." Motor control means 184A drives motor generators MG1 and MG2 (motor and

generator) according to signal DPL (step S20).

Fig. 12 is a flowchart illustrating details of the operation in step S10 shown in Fig. 11. Referring to Fig. 12, upon the start of a series of operations, precharge control means 184B of control CPU 184 receives signal STON from start key 186 (step S101). According to signal STON, precharge control means 184B generates signal SE1 and outputs the generated signal to relay 40. System relays SMR1 and SMR3 of relay 40 are rendered ON according to signal SE1 (step S102). DC power supply 30 is thus connected via resistor R1 between neutral point M1 of three-phase coil 10 and neutral point M2 of three-phase coil 11. DC power supply 30 then supplies a DC current to capacitor 50 via resistor R1, three-phase coil 10 and diodes D1, D3 and D5. In other words, when system relays SMR1 and SMR3 are made ON, DC power supply 30 supplies the DC current via resistor R1 to capacitor 50. Thus, even if DC power supply 30 is connected between neutral points M1 and M2 according to signal STON, an inrush current flowing to capacitor 50 can be prevented.

After this, precharge control means 184B determines whether or not voltage Vc from voltage sensor 51 is equal to or higher than voltage Vb from voltage sensor 32 (step S103). If voltage Vc is not equal to or higher than voltage Vb, the series of operations proceeds to step S111. If voltage Vc is equal to or higher than voltage Vb, the series of operations proceeds to step S104.

The determination as to whether or not voltage Vc is equal to or higher than voltage Vb is made in step S103 for the following reason. When system relays SMR1 and SMR3 are made ON in step S102, DC power supply 30 supplies the DC current to capacitor 50 as described above. Then, when DC power supply 30 is connected between neutral points M1 and M2, terminal-to-terminal voltage Vc of capacitor 50 increases at least to voltage Vb which is the output voltage of DC power supply 30.

However, if there is any failure like break in the circuit portion between DC power supply 30 and capacitor 50, voltage Vc does not reach voltage Vb. Then, in step S103 the determination is made as to whether voltage Vc is equal to or higher than

voltage Vb so as to ascertain that DC power supply 30 normally supplies the DC current to capacitor 50.

Accordingly, if it is determined that voltage Vc is equal to or higher than voltage Vb in step S103, which ensures that DC power supply 30 is connected between neutral points M1 and M2 or that the circuit portion between DC power supply 30 and capacitor 50 normally functions.

If it is determined that voltage Vc is equal to or higher than voltage Vb in step S103, precharge control means 184B generates signal SE2 and outputs the generated signal to relay 40. System relay SMR2 of relay 40 is rendered ON according to signal SE2, and system relay SMR1 is rendered OFF after system relay SMR2 is made ON (step S104). Then, driving of inverters 181 and 182 is allowed (step S105) so that precharge control means 184B generates signal PWMPC1 or PWMPC2 based on voltages Vb and Vc by the above-described method and outputs the generated signal to inverter 181 or 182.

In this case, if voltage Vb is increased by means of inverter 181 only, precharge control means 184B generates signal PWMPC1 to output the signal to inverter 181 and, if voltage Vb is increased by means of inverter 182 only, precharge control means 184B generates signal PWMPC2 to output the signal to inverter 182.

Specifically, when voltage Vb is increased by means of inverter 181 only, inverter 181 receives signal PWMPC1 and then NPN transistors Q2, Q4 and Q6 are simultaneously turned on/off according to signal PWMPC1. An electric power with its amount determined depending on the period in which NPN transistors Q2, Q4 and Q6 are in the ON state is accumulated in three-phase coils 10 and 11, and a DC voltage with its amount determined depending on the accumulated power is supplied to capacitor 50.

When voltage Vb is increased by means of inverter 182 only, inverter 182 receives signal PWMPC2 and then NPN transistors Q7, Q9 and Q11 are simultaneously turned on/off according to signal PWMPC2. An electric power with its amount determined depending on the period in which NPN transistors Q7, Q9 and Q11 are in

the ON state is accumulated in three-phase coils 10 and 11, and a DC voltage with its amount determined depending on the accumulated power is supplied to capacitor 50.

In this way, the voltage step-up operation for increasing voltage V_b is carried out (step S106).

5 Precharge control means 184B thereafter determines whether or not voltage V_c from voltage sensor 51 is equal to or higher than a predetermined voltage V_{std} (step S107) and, if voltage V_c is not equal to or higher than predetermined voltage V_{std} , the series of operations proceeds to step S111.

10 On the other hand, if voltage V_c is equal to or higher than predetermined voltage V_{std} , driving of inverter 183 is allowed (step S108). Then, according to signal PWMPC1 or PWMPC2, inverter 181 or 182 continues to increase voltage V_b and supplies the increased DC voltage to capacitor 50. In other words, a DC/DC converter constituted of three-phase coils 10 and 11 and inverter 181 or 182 is started to be driven (step S109).

15 Accordingly, precharge control means 184B generates signal DPL and outputs this signal to motor control means 184A and display unit 190. According to signal DPL, display unit 190 displays the indication "READY" (step S110). After this, the series of operations proceeds to step S201 shown in Fig. 13.

20 If it is determined in step S103 that voltage V_c is not equal to or higher than voltage V_b or if it is determined in step S107 that voltage V_c is not equal to or higher than predetermined voltage V_{std} , precharge control means 184B generates signal ERR and outputs this signal to motor control means 184A and display unit 190. According to signal ERR, display unit 190 displays the indication "ERR" (step S111). Then, the series of operations of power output apparatus 100 is completed.

25 If it is determined in step S103 that voltage V_c is not equal to or higher than voltage V_b , this determination means that voltage V_b output from DC power supply 30 is not applied to the terminals of capacitor 50, and thus means the presence of a failure in the circuit portion between DC power supply 30 and capacitor 50. In such a case, it

is impossible to drive motor generators MG1 and MG2 even if the operations are continued. Therefore, the indication "ERR" is displayed.

5 If it is determined in step S107 that voltage V_c is not equal to or higher than predetermined voltage V_{std} , this determination means that voltage V_b from DC power supply 30 is not increased to predetermined voltage V_{std} and thus means that there is a failure in three-phase coils 10 and 11 and NPN transistors Q2, Q4, Q6, Q7, Q9 and Q11. In such a case as well, it is impossible to drive motor generators MG1 and MG2 even if the operations are continued. Therefore, the indication "ERR" is displayed.

10 Fig. 13 is a flowchart illustrating details of the operation in step S20 shown in Fig. 11. After step S110 shown in Fig. 12, motor control means 184A receives a driver request torque. Specifically, motor control means 184A receives accelerator position AP, shift position SP and brake position BP (step S201). Then, motor control means 184A receives such system information as the number of revolutions, the temperature and the capacity of DC power supply 30 (SOC (State Of Charge) of the battery) (step S202).

15 Motor control means 184A thereafter calculates an engine command power, generator command torque $TR1$ and motor command torque $TR2$ based on various signals received in steps S201 and S202 (step S203). Then, motor control means 184A calculates the number of revolutions $MRN1$ of motor generator MG1 (generator) based on rotation angle θ_s from resolver 139 and calculates the number of revolutions $MRN2$ of motor generator MG2 (motor) based on rotation angle θ_r from resolver 149.

20 Then, motor control means 184A multiplies generator command torque $TR1$ and motor command torque $TR2$ calculated in step S203 by the number of revolutions $MRN1$ and $MRN2$ respectively to calculate generator power P_g and motor power P_m (step S204). Motor control means 184A determines whether the sum of generator power P_g and motor power P_m , $P_g + P_m$, is zero or not (step S205) and, if the sum $P_g + P_m$ is not zero, further determines whether relay 40 is made ON or not in the operation preceding this operation shown in the flowchart (step S206).

If it is determined in step S206 that relay 40 is not made ON in the preceding operation, control CPU 184 generates signal SE2 and outputs the signal to relay 40. Then, system relays SMR2 and SMR3 of relay 40 are made ON so that DC power supply 30 is connected to respective neutral points M1 and M2 of three-phase coils 10 and 11 (step S207). If it is determined in step S206 that relay 40 is made ON in the preceding operation or after step S207, subtracter 1852, PI control unit 1853, battery-current predictive calculation unit 1851, adder/subtracter 1854 and PI control unit 1855 calculate a potential difference between respective neutral points M1 and M2 of three-phase coils 10 and 11, namely the neutral-point voltage command of the 2Y motor, according to the above-described method (step S208). After this, this process proceeds to step S213.

If it is determined in step S205 that the sum $P_g + P_m$ is zero, motor control means 184A further determines, based on battery current BCRT from current sensor 31, whether the battery current is zero or not (step S209). Then, if it is determined in step S209 that the battery current is not zero, the process proceeds to the above-described step S208.

If it is determined in step S209 that the battery current is zero, motor control means 184A determines whether relay 40 is made OFF in the preceding operation (step S210). If relay 40 is not made off, signal SE at L level is generated and output to relay 40. Accordingly, relay 40 is made OFF and DC power supply 30 is disconnected from respective neutral points M1 and M2 of three-phase coils 10 and 11 (step S211). If it is determined in step S210 that relay 40 is made OFF in the preceding operation or after step S211, subtracter 1852, PI control unit 1853, battery-current predictive calculation unit 1851, adder/subtracter 1854 and PI control unit 1855 determine potential difference V_{012} between respective neutral points M1 and M2 of three-phase coils 10 and 11 as zero, namely determines the neutral-point voltage command of the 2Y motor as zero (step S212).

After step S208, with DC power supply 30 connected between neutral points

M1 and M2, the generator (motor generator MG1) and the motor (motor generator MG2) are driven (step S213). After step S212, with DC power supply 30 disconnected from neutral points M1 and M2, the generator (motor generator MG1) and the motor (motor generator MG2) are driven (step S213).

5 The procedure through steps S205, S209-S212 and S213 is a procedure through which the generator (motor generator MG1) and the motor (motor generator MG2) are driven while DC power supply 30 is disconnected from neutral points M1 and M2, namely a procedure through which motor generator MG2 is driven by the electric power generated by motor generator MG1. In such a mode, if DC power supply 30 is
10 connected between neutral points M1 and M2, a voltage applicable to each phase coil of three-phase coils 10 and 11 of motor generator MG1 is $V_c - V_b$, resulting in a decrease in power-generation efficiency of motor generator MG1.

 Since motor generator MG2 is a motor which serves to drive the drive wheels of a hybrid vehicle, it is preferable, for allowing the hybrid vehicle to run smoothly, that
15 the number of revolutions can be controlled over a wide range. Then, in order to improve the power-generation efficiency of motor generator MG1 and control the number of revolutions of motor generator MG2 over a wide range, DC power supply 30 is disconnected from neutral points M1 and M2 in the mode in which motor generator MG2 is driven by the electric power generated by motor generator MG1.

20 The procedure through steps S206-S208 and S213 is a procedure through which the generator (motor generator MG1) and the motor (motor generator MG2) are driven while DC power supply 30 is connected to neutral points M1 and M2. Through this procedure, potential difference V_{012} between neutral points M1 and M2 is increased/decreased to allow motor generator MG1 to increase voltage V_b from DC
25 power supply 30 to charge capacitor 50, or decreases the terminal-to-terminal voltage of capacitor 50 to charge DC power supply 30. Such voltage-step-up and voltage-step-down operations are carried out by motor generator MG1 which does not output the torque to be used for driving the drive wheels of the hybrid vehicle. Thus,

the efficiency of motor generator MG2 which drives the drive wheels can be made maximum.

Power output apparatus 100 has a feature as described above that, prior to driving of the generator (motor generator MG1) and the motor (motor generator MG2), capacitor 50 which is provided on the input side of inverters 181-183 is precharged and, upon completion of the precharging of capacitor 50, the generator (motor generator MG1) and the motor (motor generator MG2) are driven. Thus, the power output apparatus can smoothly be started.

Regarding power output apparatus 100, as described above, in the mode that the electric power generated by the generator (motor generator MG1) is used to drive the motor (motor generator MG2), DC power supply 30 is disconnected from neutral points M1 and M2 so as to improve the power-generation efficiency of the generator (motor generator MG1) and allow the motor (motor generator MG2) to operate over a wide range and, in the mode that the electric power generated by the generator (motor generator MG1) is not used to drive the motor (motor generator MG2), motor generator MG1, which does not drive the drive wheels, performs voltage step-up and step-down operations on the DC voltage. Power output apparatus 100 can thus be applied to the hybrid vehicle to allow the hybrid vehicle to run smoothly.

It is noted here that a motor driving method of the present invention is a method of driving motor generators MG1 and MG2 in accordance with the flowcharts shown in Figs. 11, 12 and 13.

Further, the drive control of the motor by control CPU 184 is actually performed by a CPU. The CPU reads, from a ROM (Read-Only Memory), a program including the steps of the flowcharts shown in Figs. 11, 12 and 13, executes the read program and thereby performs the drive control of motor generators MG1 and MG2 in accordance with the flowcharts shown in Figs. 11, 12 and 13. Thus, the ROM corresponds to a computer (CPU)-readable recording medium having the program recorded thereon that includes the steps of the flowcharts shown in Figs. 11, 12 and 13.

Referring again to Fig. 3, operations of power output apparatus 100 which is mounted on a hybrid vehicle are described. Specifically, descriptions are given below of an operation of the power output apparatus when the engine of the hybrid vehicle is started, an operation thereof when the hybrid vehicle is started, an operation thereof
5 when the vehicle is in a light-load running mode, an operation thereof when the vehicle is in a medium-speed and light-load running mode, an operation thereof when the vehicle is in an acceleration/rapid acceleration mode, an operation thereof when the vehicle is in a low- μ road running mode and an operation thereof when the vehicle is in a deceleration/braking mode.

10 Power output apparatus 100 operates as described below when the engine of the hybrid vehicle is started. Upon the start of a series of steps of the operation, control CPU 184 generates, in response to signal STON from start key 186, signal SE1 at H level and outputs this signal to relay 40. System relays SMR1 and SMR3 of relay 40 are rendered ON according to signal SE1 at H level. Then, control
15 CPU 184 determines whether or not voltage Vc from voltage sensor 51 is equal to or higher than voltage Vb from voltage sensor 32 and, if voltage Vc is not equal to or higher than voltage Vb, control CPU 184 generates signal ERR and outputs this signal to display unit 190. Display unit 190 then displays the indication "ERROR" according to signal ERR.

20 If voltage Vc is equal to or higher than voltage Vb, control CPU 184 generates signal SE2 and outputs the signal to relay 40. Then, system relay SMR2 of relay 40 is rendered ON according to signal SE2 while system relay SMR1 is rendered OFF according to signal SE2 after system relay SMR2 is made ON.

Control CPU 184 thereafter generates signal PWMPC1 or PWMPC2
25 through the above-described method and outputs the signal to inverter 181 or 182. According to signal PWMPC1 or PWMPC2, inverter 181 or 182 increases output voltage Vb of DC power supply 30 to precharge capacitor 50 to predetermined voltage Vstd or higher.

Control CPU 184 then determines whether or not voltage V_c from voltage sensor 51 is equal to or higher than predetermined voltage V_{std} and, if voltage V_c is not equal to or higher than predetermined voltage V_{std} , control CPU 184 generates signal ERR and outputs the signal to display unit 190. Then, display unit 190
5 displays the indication "ERROR" according to signal ERR.

If voltage V_c is equal to or higher than predetermined voltage V_{std} , control CPU 184 generates signal DPL indicating that capacitor 50 is precharged and outputs the generated signal to display unit 190. Then, display unit 190 displays the indication "READY" according to signal DPL.

10 Control CPU 184 then generates a torque command value TR_{11} (a kind of torque command value TR_1) and the number of revolutions of the motor (hereinafter referred to as "motor revolution number") MRN_1 for using motor generator MG_1 to start engine 150. Control CPU 184 calculates, based on the generated torque
15 command value TR_{11} , current command values I_{d1}^* and I_{q1}^* of currents to be flown through the d-axis and q-axis of motor generator MG_1 and voltage command value V_c^* of capacitor 50. Further, control CPU 184 receives motor currents $MCRT_{11}$ and $MCRT_{12}$ from current sensors 12 and 13, voltage V_c from voltage sensor 51 and rotation angle θ_s from resolver 139, and generates signals $PWMI_1$ and $PWMI_2$ in the
20 above-described way based on the received motor currents $MCRT_{11}$ and $MCRT_{12}$, voltage V_c and rotation angle θ_s as well as the calculated current command values I_{d1}^* and I_{q1}^* and voltage command value V_c^* . Then, control CPU 184 outputs the generated signals $PWMI_1$ and $PWMI_2$ to inverters 181 and 182 respectively.

Accordingly, NPN transistors Q1-Q6 of inverter 181 are turned on/off by signal $PWMI_1$, and NPN transistors Q7-Q12 of inverter 182 are turned on/off by signal
25 $PWMI_2$. Then, inverters 181 and 182 increase voltage V_b which is output from DC power supply 30 to charge capacitor 50 and thereby adjust terminal-to-terminal voltage V_c of capacitor 50 to voltage command value V_c^* , and convert a DC voltage from capacitor 50 into an AC voltage based on signals $PWMI_1$ and $PWMI_2$ to apply the

resultant voltage to three-phase coils 10 and 11.

Motor generator MG1 is thus driven to output a torque designated by torque command value TR11, and the torque which is output from motor generator MG1 is transmitted to crankshaft 156 via sun gear shaft 125, planetary gear 120 and carrier shaft 127. Then, crankshaft 156 is rotated at motor revolution number MRN1 to start engine 150. Accordingly, this operation of power output apparatus 100, which is performed when the engine of the hybrid vehicle is started, is completed.

Power output apparatus 100 operates as described below when the hybrid vehicle starts running. Upon the start of a series of steps of the operation, control CPU 184 receives a run-start signal from an external ECU (Electrical Control Unit). In response to the run-start signal, control CPU 184 generates a torque command value TR21 (a kind of torque command value TR2) and a motor revolution number MRN2 for using motor generator MG2 to start the vehicle, and calculates current command values I_{d2}^* and I_{q2}^* to be flown through the d-axis and q-axis of motor generator MG2 based on the generated torque command value TR21.

Control CPU 184 further generates a torque command value TR12 (a kind of torque command value TR1) and motor revolution number MRN1 for allowing motor generator MG1 to function as a generator by using the rotational force of engine 150 which has been started. Then, based on the generated torque command value TR12, control CPU 184 calculates current command values I_{d1}^* and I_{q1}^* to be flown through the d- and q-axes of motor generator MG1 as well as voltage command value V_c^* of capacitor 50.

Control CPU 184 calculates power P_m of the motor (motor generator MG2) from torque command value TR21 and motor revolution number MRN2 and calculates power P_g of the generator (motor generator MG1) from torque command value TR12 and motor revolution number MRN1. Control CPU 184 determines whether the sum of power P_m of the motor and power P_g of the generator, $P_m + P_g$, is zero or not. If the sum $P_m + P_g$ is not zero, CPU 184 determines whether relay 40 is made ON or not.

Since relay 40 is made ON at the start of engine 150, control CPU 184 calculates, based on the calculated current command values I_{d1}^* and I_{q1}^* and voltage command value V_c^* as well as voltage V_c from voltage sensor 51, potential difference V_{012} for generating electric power by three-phase coils 10 and 11 while decreasing the DC voltage of capacitor 50 to charge DC power supply 30. Control CPU 184 adds the calculated potential difference V_{012} to voltages V_{u1} , V_{v1} , V_{w1} , V_{u2} , V_{v2} and V_{w2} to be applied to respective phase coils of three-phase coils 10 and 11 that are calculated based on current command values I_{d1}^* and I_{q1}^* , motor currents $MCRT11$ and $MCRT12$ from current sensors 12 and 13 and rotation angle θ_s from resolver 139 thereby generating signals $PWMC1$ and $PWMC2$, and outputs the generated signals to inverters 181 and 182 respectively.

Further, control CPU 184 receives motor current $MCRT2$ from current sensor 14 and rotation angle θ_r from resolver 149 to generate signal $PWMI3$ in the above-described way based on the received motor current $MCRT2$ from current sensor 14 and rotation angle θ_r from resolver 149 as well as the calculated current command values I_{d2}^* and I_{q2}^* , and outputs the generated signal to inverter 183.

Accordingly, inverters 181 and 182 convert an AC voltage generated by three-phase coils 10 and 11 according to signals $PWMC1$ and $PWMC2$ into a DC voltage so as to charge capacitor 50 while decreasing a DC voltage from capacitor 50 so as to charge DC power supply 30. Inverter 183 converts a DC voltage from capacitor 50 into an AC voltage according to signal $PWMI3$ to drive motor generator $MG2$. Then, motor generator $MG2$ generates a torque designated by torque command value $TR21$, transmits the generated torque to power transmission gear 111 via ring gear shaft 126, planetary gear 120, power-feed gear 128 and chain belt 129 and thereby drives the drive wheels. The hybrid vehicle thus starts running.

In this case, although motor generator $MG1$ performs the voltage-step-down operation, the starting performance of the hybrid vehicle never deteriorates since motor generator $MG1$ does not drive the drive wheels.

If the sum of power P_m of the motor and power P_g of the generator, $P_m + P_g$, is zero, control CPU 184 further determines whether battery current BCRT from current sensor 31 is zero or not. If battery current BCRT is not zero, the above-described procedure which is taken when the sum $P_m + P_g$ is not zero is followed. If battery
5 current BCRT from current sensor 31 is zero, control CPU 184 determines whether relay 40 is made OFF or not. In this case, since relay 40 has remained ON since the start of the engine 150, control CPU 184 generates signal SE at L level and outputs the generated L level signal to relay 40. Accordingly, relay 40 (all of the system relays SMR1-SMR3) is made OFF and DC power supply 30 is disconnected from neutral
10 points M1 and M2.

CPU 184 then sets potential difference V012 between neutral points M1 and M2 to zero and, based on the calculated current command values I_{d1}^* and I_{q1}^* , motor currents MCRT11 and MCRT12 from current sensors 12 and 13 and rotation angle θ_s from resolver 139, generates signals PWM1C1 and PWM1C2 to output the generated
15 signals to inverters 181 and 182.

Further, control CPU 184 receives motor current MCRT2 from current sensor 14 and rotation angle θ_r from resolver 149 and, based on the received motor current MCRT2 and rotation angle θ_r as well as the calculated current command values I_{d2}^* and I_{q2}^* , generates signal PWM13 in the above-described way to output the generated
20 signal to inverter 183.

Accordingly, inverters 181 and 182 convert an AC voltage generated by three-phase coils 10 and 11 according to signals PWM1C1 and PWM1C2 into a DC voltage so as to charge capacitor 50. Inverter 183 converts a DC voltage from capacitor 50 into an AC voltage according to signal PWM13 so as to drive motor
25 generator MG2. Motor generator MG2 generates a torque designated by torque command value TR21, transmits the generated torque via ring gear shaft 126, planetary gear 120, power-feed gear 128 and chain belt 129 to power transmission gear 111 and thereby drives the drive wheels so that the hybrid vehicle starts running.

In this case, since DC power supply 30 is disconnected from neutral points M1 and M2, the power-generation efficiency of motor generator MG1 is enhanced. Receiving the power generated by motor generator MG1 with its power-generation efficiency enhanced, motor generator MG2 operates over a wide range. Accordingly, the hybrid vehicle starts running smoothly.

Then, the operation of the power output apparatus 100 when the hybrid vehicle starts running is completed.

Power output apparatus 100 operates as described below when the hybrid vehicle is in the light-load running mode. Upon the start of a series of steps of the operation, control CPU 184 receives a signal indicative of the light-load running mode from the external ECU. In response to the signal indicative of the light-load running mode, control CPU 184 generates a torque command value TR22 (a kind of torque command value TR2) and motor revolution number MRN2 for driving the front wheels of the hybrid vehicle by motor generator MG2 only. Control CPU 184 then calculates current command values I_{d2}^* and I_{q2}^* to be flown through the d- and q-axes of motor generator MG2 based on the generated torque command value TR22. Control CPU 184 receives motor current MCRT2 from current sensor 14 and rotation angle θ_r from resolver 149. Based on the received motor current MCRT2 and rotation angle θ_r as well as the calculated current command values I_{d2}^* and I_{q2}^* , control CPU 184 generates signal PWMI3 in the above-described way and outputs the signal to inverter 183.

According to signal PWMI3, inverter 183 converts a DC voltage from capacitor 50 into an AC voltage to drive motor generator MG2. Motor generator MG2 generates a torque designated by torque command value TR22, transmits the generated torque to power transmission gear 111 via ring gear shaft 126, planetary gear 120, power-feed gear 128 and chain belt 129, and thereby drives the drive wheels so that the hybrid vehicle runs under light load. Accordingly, the operation of power output apparatus 100 when the hybrid vehicle is in the light-load running mode is

completed.

Power output apparatus 100 operates as described below when the hybrid vehicle is in the medium-speed and light-load mode. The operation of power output apparatus 100 in this mode is identical to the operation which is carried out when engine
5 150 of the hybrid vehicle is started as described above.

Power output apparatus 100 operates as described below when the hybrid vehicle is in the acceleration/rapid acceleration mode. Upon the start of a series of steps of the operation, control CPU 184 receives from the external ECU a signal indicative of the acceleration/rapid acceleration mode. In response to the signal
10 indicative of the acceleration/rapid acceleration mode, control CPU 184 generates a torque command value TR23 (a kind of torque command value TR2) and motor revolution number MRN2 for using motor generator MG2 for acceleration/rapid acceleration. Then, based on the generated torque command value TR23, control CPU
15 184 calculates current command values I_{d2}^* and I_{q2}^* to be flown through the d- and q-axes of motor generator MG2.

Further, control CPU 184 generates a torque command value TR13 (a kind of torque command value TR1) and motor revolution number MRN1 for allowing motor generator MG1 to function as a generator which generates electric power from the rotational force of engine 150. Based on the generated torque command value TR13,
20 control CPU 184 calculates current command values I_{d1}^* and I_{q1}^* to be flown through the d- and q-axes of motor generator MG1 and voltage command value V_c^* of capacitor 50.

Control CPU 184 further calculates power P_m of the motor (motor generator MG2) from torque command value TR23 and motor revolution number MRN2 as well
25 as power P_g of the generator (motor generator MG1) from torque command value TR13 and motor revolution number MRN1. Then, control CPU 184 determines whether the sum of power P_m of the motor and power P_g of the generator, $P_m + P_g$, is zero or not. If the sum $P_m + P_g$ is not zero, control CPU 184 determines whether

relay 40 is made ON or not. If relay 40 is not made ON, control CPU 184 generates signal SE at H level and outputs the generated signal to relay 40. Accordingly, DC power supply 30 is connected to neutral points M1 and M2.

5 After this, based on the calculated current command values I_{d1}^* and I_{q1}^* and voltage command value V_c^* as well as voltage V_c supplied from voltage sensor 51, control CPU 184 calculates potential difference V_{012} for generating electric power by three-phase coils 10 and 11 while decreasing a DC voltage of capacitor 50 to charge DC power supply 30. Then, control CPU 184 adds the calculated potential difference V_{012} to voltages V_{u1} , V_{v1} , V_{w1} , V_{u2} , V_{v2} and V_{w2} to be applied to respective phase
10 coils of three-phase coils 10 and 11 that are calculated based on current command values I_{d1}^* and I_{q1}^* , motor currents MCRT11 and MCRT12 from current sensors 12 and 13 and rotation angle θ_s from resolver 139, thereby generates signals PWM C1 and PWM C2 and outputs the signals to inverters 181 and 182 respectively.

Further, control CPU 184 receives motor current MCRT2 from current sensor
15 14 and rotation angle θ_r from resolver 149, generates signal PWM I3 in the above-described way based on the received motor current MCRT2 and rotation angle θ_r and the calculated current command values I_{d2}^* and I_{q2}^* , and outputs the generated signal to inverter 183.

Inverters 181 and 182 thus convert an AC voltage generated by three-phase
20 coils 10 and 11 according to signals PWM C1 and PWM C2 into a DC voltage so as to charge capacitor 50 and decreases a DC voltage from capacitor 50 so as to charge DC power supply 30. Inverter 183 converts a DC voltage from capacitor 50 into an AC voltage according to signal PWM I3 so as to drive motor generator MG2. Motor generator MG2 generates a torque designated by torque command value TR23 and
25 transmits the generated torque via ring gear shaft 126, planetary gear 120, power-feed gear 128 and chain belt 129 to power transmission gear 111 so as to drive the drive wheels so that the hybrid vehicle accelerates/rapidly accelerates.

In this case, although motor generator MG1 performs the voltage-step-down

operation, the starting performance of the hybrid vehicle never deteriorates since motor generator MG1 does not drive the drive wheels.

5 If the sum of power P_m of the motor and power P_g of the generator, $P_m + P_g$, is zero, control CPU 184 further determines whether battery current BCRT from current sensor 31 is zero or not. If battery current BCRT is not zero, the above-described procedure when the sum $P_m + P_g$ is not zero is followed. If battery current BCRT from current sensor 31 is zero, control CPU 184 determines whether relay 40 is made OFF or not. If relay 40 is not made OFF, control CPU 184 generates signal SE at L level to output the L level signal to relay 40. Relay 40 (all of system relays
10 SMR1-SMR3) is thus made OFF so that DC power supply 30 is disconnected from neutral points M1 and M2.

After this, control CPU 184 sets potential difference V012 between neutral points M1 and M2 to zero and, based on the calculated current command values I_{d1}^* and I_{q1}^* , motor currents MCRT11 and MCRT12 from current sensors 12 and 13 and
15 rotation angle θ_s from resolver 139, generates signals PWM1 and PWM2 to output the signals to inverters 181 and 182 respectively.

Control CPU 184 receives motor current MCRT2 from current sensor 14 and rotation angle θ_r from resolver 149 and, based on the received motor current MCRT2 and rotation angle θ_r and the calculated current command values I_{d2}^* and I_{q2}^* ,
20 generates signal PWM3 in the above-described way and outputs the generated signal to inverter 183.

Then, inverters 181 and 182 convert an AC voltage generated by three-phase coils 10 and 11 according to signals PWM1 and PWM2 into a DC voltage so as to charge capacitor 50. Inverter 183 converts a DC voltage from capacitor 50 into an AC
25 voltage according to signal PWM3 to drive motor generator MG2. Motor generator MG2 generates a torque designated by torque command value TR23 and transmits the generated torque via ring gear shaft 126, planetary gear 120, power-feed gear 128 and chain belt 129 to power transmission gear 111 so as to drive the drive wheels so that the

hybrid vehicle accelerates/rapidly accelerates.

In this case, since DC power supply 30 is disconnected from neutral points M1 and M2, the power-generation efficiency of motor generator MG1 is enhanced.

Receiving the power generated by motor generator MG1 with its power-generation efficiency enhanced, motor generator MG2 operates over a wide range. Accordingly, the hybrid vehicle accelerates/rapidly accelerates smoothly. The operation of power output apparatus 100 in the acceleration/rapid acceleration mode of the hybrid vehicle is thus completed.

Power output apparatus 100 operates as described below when the hybrid vehicle is in the low- μ road running mode. Upon the start of a series of steps of the operation, control CPU 184 receives a signal indicative of the low- μ road running mode from the external ECU. In response to the signal indicative of the low- μ road running mode, control CPU 184 generates a torque command value TR24 and motor revolution number MRN2 for driving motor generator MG2 in a regenerative mode and, based on the generated torque command value TR24, calculates current command values Id2* and Iq2* to be flown through the d- and q-axes of motor generator MG2.

Control CPU 184 then generates signal PWMC3 based on motor current MCRT2 from current sensor 14, rotation angle θ_r from resolver 149 and the calculated current command values Id2* and Iq2*, and outputs the generated signal to inverter 183.

According to signal PWMC3, inverter 183 converts an AC voltage generated by motor generator MG2 into a DC voltage so as to charge capacitor 50. The operation of power output apparatus 100 when the hybrid vehicle is in the low- μ road running mode is accordingly completed.

Power output apparatus 100 operates as described below when the hybrid vehicle is in the deceleration/braking mode. In this case, since the power is recovered, in the form of electric energy, from the energy generated when the

vehicle is running, motor generator MG2 is driven in the regenerative mode. Therefore, the operation of power output apparatus 100 in this case is identical to that in the low- μ road running mode.

5 It is noted here that, according to the description above, capacitor 50 is precharged to a predetermined voltage by using all of the U-phase arm 15, V-phase arm 16 and W-phase arm 17 of inverter 181 or all of the U-phase arm 18, V-phase arm 19 and W-phase arm 20 of inverter 182. However, the present invention is not limited to the above-described manner. Specifically, one arm selected from U-phase arm 15, V-phase arm 16 and W-phase arm 17 of inverter 181 or one arm
10 selected from U-phase arm 18, V-phase arm 19 and W-phase arm 20 of inverter 182 may be used to increase voltage V_b from DC power supply 30 and thereby precharge capacitor 50 to a predetermined voltage.

Moreover, according to the present invention, U-phase arm 15, V-phase arm 16 and W-phase arm 17 of inverter 181 or U-phase arm 18, V-phase arm 19
15 and W-phase arm 20 of inverter 182 may be switched in a predetermined order to increase voltage V_b from DC power supply 30 and thereby precharge capacitor 50 to a predetermined voltage. In this way, deterioration of U-phase arm 15, V-phase arm 16 and W-phase arm 17 of inverter 181 or U-phase arm 18, V-phase arm 19 and W-phase arm 20 of inverter 182 can be reduced.

20 Further, according to the description above, precharge control means 184B determines that voltage V_c is equal to or higher than voltage V_b and thereby ascertains that DC power supply 30 is surely connected between neutral points M1 and M2. The present invention, however, is not limited to this manner. Specifically, the reference voltage for allowing precharge control means 184B to
25 ascertain that DC power supply 30 is connected between neutral points M1 and M2 may be any voltage value except for voltage V_b .

In addition, predetermined voltage V_{std} which is used for ascertaining that precharging of capacitor 50 is completed may be any voltage which indicates that

voltage V_b of the DC power supply is increased.

According to the present invention, three-phase coils 10 and 11 and inverter 181 or three-phase coils 10 and 11 and inverter 182 may constitute a "DC/DC converter."

5 Further, according to the present invention, one of the phase coils of three-phase coil 10, one of the phase coils of three-phase coil 11 and a corresponding arm of the arms of inverter 181 (any of U-phase arm 15, V-phase arm 16 and W-phase arm 17) may constitute a "DC/DC converter."

10 Further, according to the present invention, one of the phase coils of three-phase coil 10, one of the phase coils of three-phase coil 11 and a corresponding arm of the arms of inverter 182 (any of U-phase arm 18, V-phase arm 19 and W-phase arm 20) may constitute a "DC/DC converter."

15 According to this embodiment, the power output apparatus includes precharge control means 184B for generating signal PWMPC1 or PWMPC2 for precharging capacitor 50 according to signal STON from the start key, inverter 181 or 182 for increasing output voltage V_b of DC power supply 30 and thereby precharging capacitor 50 according to signal PWMPC1 or PWMPC2 and motor control means 184A for driving motor generators MG1 and MG2 after the precharging of capacitor 50 is completed. The power output apparatus can thus be
20 started smoothly.

Moreover, when the engine is started, a high inverter input voltage is applied to inverters 181-183 so that motor generators MG1 and MG2 can be driven with a high output and a high efficiency. The hybrid vehicle having power output apparatus 100 mounted thereon can thus be improved in fuel efficiency.

25 Moreover, precharging of capacitor 50 increases the inverter input voltage to inverters 181-183 so that vibrations in crank-up of the engine can be reduced.

According to this embodiment, the power output apparatus includes motor generator MG1, motor generator MG2, the DC power supply, the relay

connecting/disconnecting the DC power supply between/from respective neutral points of two three-phase coils of motor generator MG1, and the control CPU which controls the relay in such a manner that, when motor generator MG2 is to be driven by electric power generated by motor generator MG1, the DC power supply
5 is disconnected from respective neutral points of the two three-phase coils of motor generator MG1. Accordingly, the power-generation efficiency of motor generator MG1 can be improved and motor generator MG2 can operate over a wide range. Moreover, since the control CPU drives motor generator MG1 in such a manner that motor generator MG1 performs the voltage-step-up or voltage-step-down
10 operation, motor generator MG2 which drives the drive wheels of the hybrid vehicle can exhibit the maximum efficiency.

Although the present invention has been described and illustrated in detail, it is clearly understood that the same is by way of illustration and example only and is not to be taken by way of limitation, the spirit and scope of the present invention being limited
15 only by the terms of the appended claims.